Hard Tissue Ablation and Modification with IR Lasers

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Infrared lasers are ideally suited for the selective and precise removal of carious dental hard tissue while minimizing the healthy tissue loss. Since the initial investigations of Stern[1] over 30 years ago, several unique laser applications have evolved for dentistry, namely laser ablation of dental hard tissue, caries inhibition treatments by localized surface heating, and surface conditioning for bonding[2]. During high intensity laser irradiation, marked chemical and physical changes may be induced in the irradiated dental enamel. These changes can have profound effects on the laser ablation/drilling process and may lead to a reduction in the ablation rate and efficiency, increase peripheral thermal damage and even lead to stalling without further removal of tissue with subsequent laser pulses. Moreover, thermal decomposition of the mineral can lead to changes in the susceptibility of the modified mineral to organic acids in the oral environment. Morphological changes may result in the formation of loosely attached layers of modified enamel that can delaminate leading to failure during the bonding to restorative materials [3, 4]. Therefore, it is important to thoroughly characterize the laser (thermal) induced chemical and crystalline changes after laser irradiation. The mineral, hydroxyapatite, found in bone and teeth contains carbonate inclusions that render it highly susceptible to acid dissolution by organic acids generated from bacteria in dental plaque. Upon heating to temperatures in excess of 400 °C, the mineral decomposes to form a new mineral phase that has increased resistance to acid dissolution[5]. Recent studies suggest that as a side effect of laser ablation, the walls around the periphery of a cavity preparation will be transformed through laser heating into a more acid resistant phase with an enhanced resistance to future decay[6]. However, poorly crystalline non-apatite phases of calcium phosphate may have an opposite effect on plaque acid resistance[7] and may increase the quantity of poorly attached grains associated with delamination failures.IR spectroscopy has been used for half a century to study the structure of bony tissue[8, 9]. Fowler and Kuroda [7, 10] used IR transmission spectroscopy to show the chemical changes induced in laser irradiated dental enamel. Recently, we demonstrated that FTIR in specular reflectance mode could be used effectively to nondestructively measure the laser-induced chemical changes in enamel and that the carbonate loss could be determined as a function of incident laser intensity[11]. However, this technique requires smooth surfaces of large area in order to acquire suitable spectra. The high brightness of the ALS enables spectra to be acquired on specific areas across ablation craters with a resolution of 10 μm.

FTIR spectroscopy was used in the specular reflectance mode for resolving thermally induced changes in dental hard tissue as a result of laser irradiation. High spatial resolution (10 μm) was used with the high brightness available on beam line 1.4.3 for these studies. IR spectra of modified bovine enamel were acquired after laser ablation using several laser wavelengths from the UV to the mid-IR. Specific areas within the laser-ablated region were examined to determine the structural and chemical composition

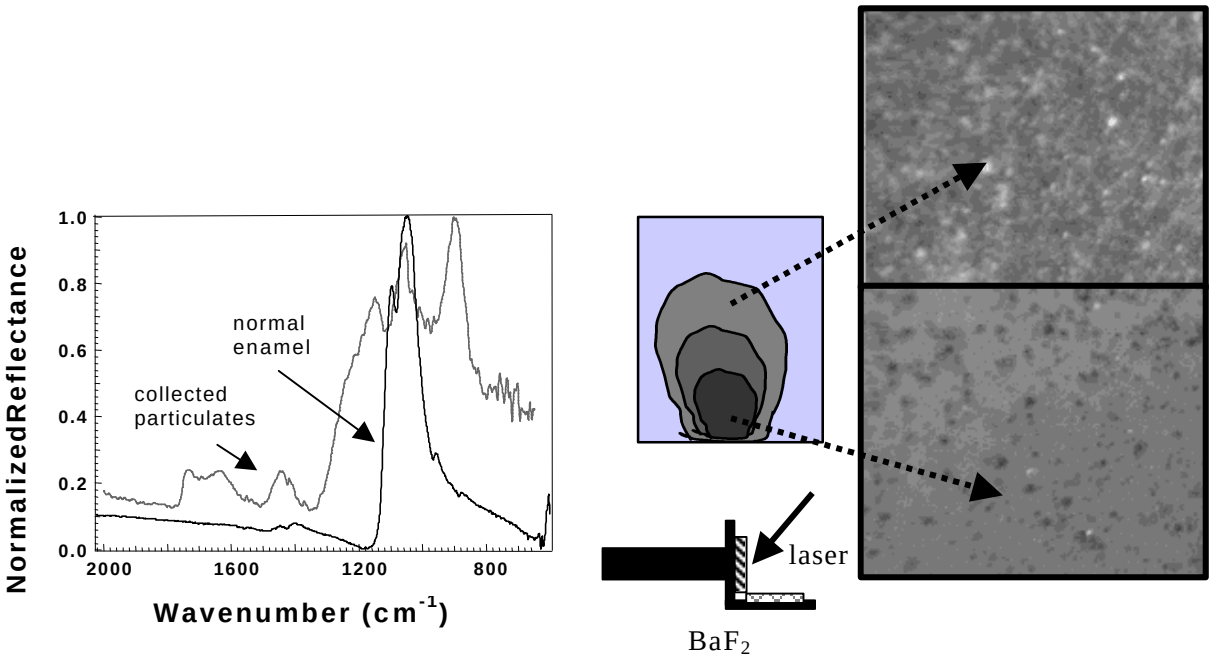

Fig. 1 Spectra of ejected particles collected in vacuum after the laser ablation of enamel using a 9.6 μm TEA CO_2 laser. The particles are deposited in a fan shaped distribution on a BaF_2 substrate. Optical images (320x) of the low density zone (top) and high density zone (bottom) are shown on the right. SR-FTIR spectra of the particles(gray) and normal enamel are shown on the left.

changes associated with the ablation process. The energy deposition and maximum temperature are greatest at the center of crater created by the ablation process and decreases with distance from the crater center. The chemical composition of the crater walls deviated significantly from that of hydroxyapatite after Er:YAG and CO_2 laser irradiation without added water. The high spatial resolution of beam line 1.4.3 allowed identification of the mineral phases present on the crater walls [12, 13] These mineral phases have not been previously reported because of the limited resolution of conventional IR spectroscopy systems.

We postulated that the non-apatite mineral phases originate from the plume of ejected material above the ablated area. In order to confirm that hypothesis, we collected the ablated mineral phases on BaF_2 substrates in vacuum. SR-FTIR spectra were used to show the distribution of phases as a function of distance from the site of laser ablation (Fig. 1). Such data confirms that the mineral phase distribution around the ablation craters is due to recondensation from the plume. We are continuing this effort with other laser wavelengths, energy deposition conditions, and quantities of water to determine the optimum ablation conditions with limited subsurface damage and improved surface conditions for bonding or resistance to environmental degradation. Supported by NIH/NIDCR R29DE12091.

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